

THE EFFECT OF RAINRATE MODELING FOR THE PREDICTION OF
SATELLITE PROPAGATION IN MALAYSIA

AYMAN.A.A. ALWARFALLI

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University Teknologi Malaysia

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DEDICATIONS

To my beloved parents, brothers, and sisters.

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ABSTRACT

By increasing number of commercial applications are being promoted for future satellites broadband services, the appearance of such systems with due to its growing demand for radio frequency spectrums. Since lower frequencies have become saturated, a transition to higher frequencies band such as Ka-band (20/30 GHz) and above has become necessary. These bands are attractive because it offers wider bandwidth, higher data rates and smaller component sizes. On the other hand, higher frequencies have more propagation problems. Attenuation caused by rain is major limitation can be a serious problem especially in the tropical regions. In Malaysia, the tropical climate effects study for higher frequency band become increasingly important. The main concern of this project is therefore, to study and analyze the measured field data of the rain attenuation within these bands. To achieve this, previous researchers measured field data are studied and analyzed to understand the behavior of signal propagation during rainfall event, particularly for Malaysia. To achieve this goal, various experiments were conducted using microwave links, satellite broadcasting receiver and rain gauges. An overview of published and proposed prediction model of rain attenuation on satellite link is discussed based on this data, the latest developments in prediction and modeling techniques presented and discussed. Moreover, a proposed prediction model of rain attenuation in Malaysia is employed and tested, in order to determine the rain attenuation of slant and terrestrial path. The project goals are extended to an adaptive prediction model of the specific attenuation, rain height and effective horizontal length. With the verifications of the proposed model using ITU-R (Study Group3), it is possible to improve the efficiency of satellite communication in Malaysia with an improved design for future broadband and multimedia satellite.

ABSTRAK

Peningkatan terhadap aplikasi komersil telah memperkembangkan lagi perkhidmatan jalur lebar satelit pada masa sekarang dan akan datang. Kemunculan sistem ini adalah seiring dengan pertambahan permintaan terhadap spektrum frekuensi radio. Memandangkan frekuensi rendah telah menjadi tepu, peralihan kepada jalur frekuensi-frekuensi tinggi seperti jalur-Ka (20/30 Ghz) dan ke atas sangat diperlukan. Jalur-jalur ini menarik kerana ianya menyediakan lebar jalur yang luas, kadar data yang tinggi dan saiz komponen yang kecil. Namun, frekuensi-frekuensi tinggi mempunyai lebih banyak masalah perambatan. Pelemahan yang disebabkan oleh hujan merupakan pembatasan utama yang boleh menyebabkan masalah yang serius terutama dikawasan-kawasan tropika. Dalam iklim tropika di malaysia, kajian pelemahan oleh hujan pada jalur berfrekuensi tinggi menjadi sangat penting. Tujuan utama projek ini dijalankan adalah untuk mengkaji pelemahan oleh hujan dalam lingkungan jalur-jalur ini. Bagi mencapai objektif ini, data-data daripada kajian terdahulu telah dianalisa untuk memahami sifat perambatan isyarat semasa hujan. Sumber-sumber untuk data ini telah diuruskan secara eksperimen menggunakan talian gelombang micro, penerima penyiaran satelit dan tolok hujan. Kajian secara umum berkaitan penulisan dan model cadangan jangkaan pelemahan oleh hujan pada perhaurgen satelit telah dibincangkan dengan berdasarkan kepada data, dan juga perkembangan-perkembangan terkini dalam penentuan dan teknik-teknik pemodelan. Cadangan model jangkaan pelemahan oleh hujan di malaysia telah digunakan dan diuji, bertujuan untuk menentukan pengecilan oleh hujan pada laluan uagak dan mendatar. Matlamat projek telah diperkembangkan lagi kepada model jangkaan penyesuaian spesifikasi pelemahan, ketinggian hujan dan laluan mendatar efektif. Dengan pengesahan model cadangan yang menggunakan ITU-R (kumpulan perbincangan 3) yang mana mengkaji keberkesanan komunikasi satelit di malaysia boleh dipertingkatkan lagi untuk tujuan rekabentuk jalur lebar satelit dan multimedia pada masa akan datang.

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LIST OF SYMBOLS

A	Attenuation
$A_{0.01}$	Attenuation at 0.01% of time
A_m	Measured attenuation
A_p	Predicted attenuation
dB	Decibel unite
f	Frequency
GHz	Giga Hertz
h_o	Rain freezing height
H_R	Rain height (km)
H_s	Height above mean sea level of the earth station (km).
k, α	Regression coefficients
km	Kilometer
L_{eff}	Effective Path length
LG	Horizontal projection of the slant path
L_o	Rain cell diameter
L	path length
m	Meter
mm	Millimeter
P (%)	Percentage in time of the year
$R_{(p)}$	Rain rate at percentage in time of the year
$r(P)$	Horizontal reduction factor of percentage in time of the year
$r_{0.01}$	Horizontal reduction factor for 0.01% time of the year
$R_{0.01}$	Rain rate at 0.01% of time of the year
$v_{0.01}$	Vertical reduction factor for 0.01% time of the year
γ_R	Specific attenuation
θ	Elevation Angle
Φ	Latitude of the earth station
τ	Polarization Tilt angel

μ_V	Statistical mean
σ_V	Standard deviation
ρ_V	Root Mean Square

LIST OF ABBREVIATIONS

C	Centigrade
DBSG5	ITU-R Study Group Three Data Bank
DTH	Direct to Home
EHF	Extremely High Frequency
EIRP	Effective Isotropic Radiating Power
FSS	Fixed Satellite Service
GEO	Geosynchronous Earth Orbit
IEEE	Institute of Electrical and Electronic Engineering
ITU-R	International Telecommunication Union Radio-Broadcasting
LEO	Low Earth Orbit
MEO	Medium Earth Orbit
MMS	Malaysia Metrological Services
RF	Radio Frequency
RMS	Root Mean Square
SHF	Super High Frequency
TRMM	Tropical Rainfall Measuring Mission
U.S	United State of America
UTM	Universiti Teknologi Malaysia
VSAT	Very Small Aperture Terminal

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Satellite communications systems become an important segment of the global telecommunication infrastructure. This includes an integration of number of applications and services use the satellites to relay radio transmissions between earth terminals. These services had traditionally been available via terrestrial networks and radio broadcastings.

With the rapid growth of the information technology there is an increasing demand for broadband satellite services, which will provide reliable transmission of information. Multi-media applications including data and video require large bandwidth and low error rates for satisfactory performance. This demand will exceed the present services existence today, and there will be increasing problems of finding the required frequency spectrum to provide the bandwidth for broadband services, which has brought saturation to the conventional frequency bands allocated for satellite services, namely L (1/2 GHz), S (2/4 GHz), and C (4/6 GHz).

New and demanding satellite applications evolved has led to utilize and exploit a higher frequencies bands such as Ka-band (20/30 GHz) and above. Spectrum at Ka-band (20/30 GHz) or higher frequencies band is great importance for broadband services. This is because it's relatively unused spectrum with no congestion problem, which offers much greater bandwidths, frequency reuse capability than the current spectrum at Ku-band (11/12 GHz), and smaller component sizes.

Satellite signal propagation above 10 GHz over an atmosphere is a subject of impairs and natural phenomena such as, gaseous attenuation, cloud and fog attenuation, and rain attenuation. Those are degrading the propagation of satellite signal on the path. Unfortunately, as frequency increases, so does the impact of atmospheric conditions on the radiowave propagation (L. J. Ippolito, 1986). That is resulted a reduction in the quality of analog transmissions, and increasing in the bit error rate of digital transmissions, which is caused a reduction on the availability, and the reliability of the satellite systems performance at higher frequencies band.

The issue of greatest importance in the study of the performance of microwave and satellite links is rain attenuation. In the design of such systems, the attenuation due to rain must be accurately accounted using prediction model to ensure the reliability and availability of the system during the rain event. Systems that are poorly designed lead to an increase in transmission errors, or worst, to an outage in the received signal (L. J. Ippolito, 1986).

The prediction model developments have to rely on rain process statistics which could contain an insufficient amount of data for long-term predictions. Especially for tropical climates which are vaguely understood of the rain fall structure as compared to climate regions in temperate regions such as North-America or Europe where the largest number of observing stations are located. Therefore, the practical solution has been discussed by Moupfouma (1994), where the rainfall rate model has been modeled to be applicable to use in tropical regions.

1.2 Project Background

Rain attenuation is one of the most fundamental limitations on the performance of the satellite links above 10 GHz. Rain attenuation caused by scattering and absorption by water droplets, causing large variations in the received signal power, with little predictability and many sudden changes (Freeman, 1997). Thus, the knowledge of the rain attenuation is extremely required for a design of a reliable satellite system. According to Lin (1977), to overcome these limitations an accurate statistical prediction model is required to improve the system performance during a heavy rain fall.

Rain attenuation researches were began by Ryde studies (1945) carried out in the year immediately following World War II. Lin (1977) developed a published prediction model based on experimental data in United State. Crane (1980) presented a model for estimating rain attenuation on either terrestrial or slant satellite paths. The development of these models has proceeded from these early studies to the present with further enhancement and improvement.

The primary goal of a rain attenuation prediction method is to achieve acceptable estimates of the attenuation incurred on the signal due to rain. According to Lin (1977), in order to predict a reliable and accurate rain prediction model, it is required to determine the one minute integration time of rain fall rate together with direct measurements of rain attenuation. Therefore, unavailability of time for reliable communication systems in a year (Outage time) has to be kept at 0.01 percent of time. This corresponds to 99.99 percent of time availability for one year (ITU-R, 1997).

Stutzman *et al.* (1986) developed a simple rain attenuation model for earth-space radio links operating at 10-35 GHz. The model takes into account the effect of wave polarization and was verified by observations in a database created from 62 experiments conducted in the U.S.A., Europe, and Japan. Goldhirsh *et al.* (1992) computed rain rate statistics and rain distributions at 20 and 30 GHz derived from a network of rain gauges along the mid-Atlantic coast over a five-year period. Dissanayake *et al.* (1997) combined rain attenuation and other types of propagation impairment along earth-satellite paths in a prediction model whose estimates of propagation impairment were compared with simultaneous-beacon and radiometer measurements.

While numerous studies have demonstrated good agreement between model predictions and field measurements in the estimates of propagation impairment, most of them have primarily focused upon regions in the middle and high latitudes such as United State of America and European countries. Those are mainly applicable to use in the regions of higher latitude.

The effect of rain is more critical for countries located in tropical and equatorial regions which experience a high rainfall rate throughout the year. According to Moupfouma (1994), when those models are applied to tropical regions the performances are lower than accepted, and the results of these researches indicate poor agreement between the measured and predicted attenuations. This has been considered due to significant climatic difference between temperate region and the tropical region.

Therefore, researches have been conducted at tropical countries such as, Brazil, Singapore, and Malaysia (Chebil, 1997), in order to get a better performance in term of more accurate results and well suited to the local climatic conditions in tropical countries. Moupfouma (1984) indicates that since the rain drops in tropical regions are larger than the temperate regions, the incidence of rainfall becomes more critical as low as 7 GHz.

In 1997, the Tropical Rainfall Measuring Mission (TRMM) satellite was launched as a joint project between the U.S.A. and Japan that carries the first space borne rain radar. Because of the rapid progress in space borne sensor technology, many studies on space-based remote sensing have also been performed in recent years.

Malaysia has a tropical climate weather which experiences a high rainfall rate throughout the year. The mean annual rain fall ranging between 2400 mm to 3200 mm per year (Chebil,1997). Geographically the rainfall pattern is greatly influenced by its oceanic surrounding. Therefore, Malaysia was involved in the world researches competition toward to the satellite system technology in order to enhance the existing satellite services and to access the globalization for the future satellite technology

Researches have been carried out in the early 1990's at Universiti Teknologi Malaysia (UTM) by Tharek (1994), Din (1997), Chebil (1997), Rafiquil (2000), Kareem, (2000), Asrul (2002), and Sum (2002). Almost all of these studies were focused on the signal propagation of the microwave links, and only limited experiments were conducted for satellite link. Recently, it has become increasingly important to develop sophisticated prediction model to improve the satellite communications services in Malaysia.

The parameters investigated in this project are mainly rain attenuation beyond the rain rate modeling. The problem of predicting attenuation by rain is quite difficult, because of non-uniform distribution of rainfall rate along the entire path length (L. A. R. Silva Mello *et al*, 2002). According to Lin (1977), the path is divided into small incremental volumes, which the rainfall is approximately uniform. The rainfall rate in each small volume is associated with a corresponding attenuation called specific attenuation, and the multiplication of the specific attenuation along the rainy path presents the total attenuation along the path.

Generally, for the microwave link path which is known as terrestrial path, the horizontal reduction factor is taken into account for inhomogeneity distribution of rainfall horizontally. Which cause the effective path length is shorter than the actual path length, where the effective path length is approximately the cell diameter length (Bruce R. E., 1997).

An effort has been developed to give a better understanding of the effective path length concept and its dependence on metrological factors and link parameters. Almost of these reduction factors were derived in purely empirical method at a number of geographical locations (Crane, 1980). According to Dissanayake (1990) based on radiometric rain attenuation measurements in Peru. The most probable cause for the overestimation of attenuation is the horizontal factor reduction factor, which is not applicable to climates dominated by tropical high rainfall rate.

Specifically, for this project the main concern is to calculate the rain attenuation along the satellite path which is known as slant path. The rain has non-uniform distributions in both horizontal and vertical directions along the slant path. That caused more difficulties to consider the horizontal reduction factor concept within the variation of the vertical structure of the rain height. Therefore, the vertical adjustment factor has been established to adapt the limitations of horizontal reduction factor.

According to Bandera *et al.* (1999), it is more applicable to use a vertical adjustments factor on the calculation of an effective path length for the slant path. Furthermore, this effective path length used to establish an accurate prediction model of the rain attenuation over the satellite path. Generally, a few studies have been conducted on the vertical adjustment factor comparing to horizontal reduction factor, these studies mainly based on meteorological radar reflectivity.

Practically, the number of terrestrial links experimental available is much higher than the satellite experimental data, which it has given the opportunity to study the usage of the horizontal reduction model as a function to develop an accurate prediction model of the slant path.

According to Goldhirsh (1979), there are high correlation between attenuation on the terrestrial path and the slant path at low elevation angel. Furthermore, for low and medium elevation angles, the horizontal variability of the specific attenuation is greater than that in the vertical plane. Therefore, an overall concentration of this project has taken into account the slant effective rainy path concept to overcome the limitation of the horizontal reduction factor which can cause the effective path to be more than the actual slant path.

According to Bandera *et al*, (1999), for high elevation angles the fixed specific attenuation concept approximation cannot be applied and the better approach is using vertical adjustment factor for the prediction of rain attenuation along the slant path. Therefore, the ultimate concern of this project is to address this issue and propose an appropriate prediction model for Malaysia tropical climate based on point rainfall modeling.

1.3 Problem Statement

The problem statements of this project are stated in the following points:

- i. The incapability of the published prediction models to be sensitive of the available knowledge of rainfall on Malaysia climate.

- ii The lack of satellite propagation studies in Malaysia, especially for higher frequencies band.
- iii. The lack of the knowledge in the vertical profile of rainfall structure.
- iv. The weakness of using surface point rainfall (rain gauges) measurements.

1.4 Objectives of the Project

The objective main approach is to develop a prediction model of the rain attenuation for slant path and terrestrial path, in order to enhance the existing satellite services at Ku-band, and to propose a new design parameter for future satellite systems at higher frequency band. The specific objectives of this project can be summarize as follow

- i. To provide an up to date review of the published and proposed rain attenuation models, and study on the performance of these models within Malaysia tropical climate and geographical parameters.
- ii. To use the local experimental data to enhance the prediction techniques for satellite path instead of using the theoretical models, those are mainly based on experimental data of temperate regions.

iii. To develop a simple and accurate rain attenuation prediction techniques in Malaysia based on rain rate modeling which included:

- Rain rate modeling.
- Specific rain attenuation.
- Effective horizontal path.
- Effective rain height.

A computer program has been developed to calculate the slant path rain attenuation and terrestrial path rain attenuation based on the actual measured attenuation strength which in turn used for comparison with available prediction models.

1.5 Project Scope and Methodology

The main contribution of this project is to study the usage of previous researches on the terrestrial path as function to develop the prediction model of slant satellite path. This is instead of using the theoretical models, which mainly based on experimental data of temperate regions. Therefore the scope of this project consists of two parts, rain attenuation prediction techniques of slant path and terrestrial path. The methodology diagram of overall project is illustrated in Figure 1.1. The scope of this project is phased to the following steps

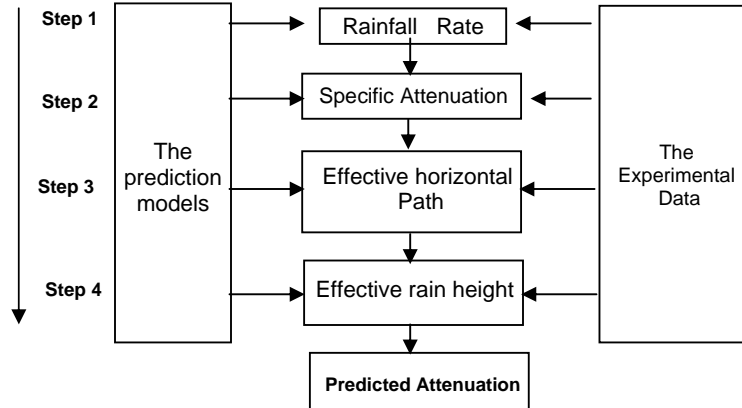


Figure 1.1: The methodology diagram of overall project

The first step is studying and comparison between the collected measured data for rainfall rate with theoretical rain rate models. According to (Z. Zhao, 2003), the agreement for the variations of rain rate per year has been taken into account to adapt the model with the respect of significant variations in site climate. This in need to indicate the best distribution model of rain fall rate within tropical climate

The second step is to obtain the specific attenuation from the short length terrestrial path (300 meters). An experimental data of terrestrial path were conducted at frequency bands 15, 18, 23, 26 and 38 GHz. These data were obtained at UTM-skudai by preceding studies [Chebil (1997), (Rafiqul (2000), and Asrul (2002)]. The empirical equations between the rainfall rate model and rain attenuation is extended to be 1 km length. That will be appropriate to estimate the specific attenuation coefficients instead of using the theoretical model to calculate the specific attenuation (Chebil, 1997). Simple regression fitting techniques are used to modify the specific attenuation model to be applicable in Malaysia, and the verifications of the proposed model have been done against other measured data at tropical region. This has been done to understand the effect of the uniform distributions of rainfall along the short path.

The Third step is to study the performance of the effective horizontal path against experimental data of a long terrestrial path (more than 1 km), with link parameters 7, 15 GHz of several path lengths measurements conducted by Kareem (2000). These terrestrial microwave links were centered at UTM-skudai and extended to several path lengths. The effective horizontal path model has been proposed based on modified specific attenuation model and rainfall rate model from previous steps results using fitting curve techniques. This has been done to understand the effect of non-uniform distributions of rainfall to calculate the effective path of the long path. On the other hand, the terrestrial path view is expressed the horizontal projection of the slant path.

The fourth step is to study the effective rain height model. That is based on different factors such as rain height 0° isotherm freezing height. Unfortunately, there are no statistical direct measurements for the rain height using radar reflectivity at UTM-skudai campus. The cost of the radar reflectivity and the availability of the statistical techniques have given the opportunity to build a suitable effective rain height model in Malaysia. The effective rain height model can be used either to built prediction model or for other climatology applications.

According to A. Pawlina (1999), the rain height can be proposed as parameter for the prediction models using statistic approach techniques in instead of using theoretical model. The effective rain height model have been proposed empirically based on point rainfall rate model and slant path experimental data in instead of using direct radar reflectivity measurements at UTM-Skudai campus. The vertical extended of rain height will be used to calculate the slant path length. Furthermore, it is used to calculate the horizontal projection length of slant path measured link attenuation at the elevation angel 70° (Sum, 2002).

The comparison between the estimated attenuation against the direct measurement at Ku-band has been done, and the effective rain height was developed.

This allows adapting for the effective rain height by a simple and accurate model to be over all averaging factor for the slant path (Bandera *et al.*, 1999). The effective slant length explains the effects of the horizontal and the vertical distributions of rainfall over the slant path. Furthermore, the effective slant path is expressed the variation of the specific attenuation along the slant path height (Crane, 1996).

The final sub-step in each steps mentioned above is comparison of the performance of the prediction models with each proposed models, which have been done against experimental data conducted at tropical regions, those have different characteristics of rainfall structure and link parameters. These experimental data have been taken from the ITU-R International Study Group Three Data Bank (DBSG3). Study and comparison of the proposed model performance against the other published models have been done, to enhance the model performance (ITU-R, 1997).

Basically the scope of work and the methodology of the study have been chosen based on assumptions for rainfall rate modeling and rain attenuation prediction technique. Table 1.1, summarizes the different assumption used in this project.

Table 1.1: The assumptions of proposed prediction model.

1. Rain Attenuation and Rain Rate Statistic	Attenuation exceeded percentage of average one year, with respect of year variation. (ITU-R, 1997).
2. Rainfall Rate	Moupfouma model (Moupfouma,1994)
3. Specific Attenuation	Modified DIN model (Din,1997)
4. Effective path length	New proposed model as function of rain rate model
5. Effective rain height	New proposed model as function of rain rate model
6. Performance Test	Using ITU-R Databank –DBSG5(ITU-R,1997)

Traditionally, during the flow of the project these assumptions has been proved and verified based on previous experiments of slant path and the new methodology has been proposed to use the terrestrial path experiments as well, in order to be suitable to predict the rain attenuation at different frequency bands in Malaysia.

1.6 Thesis Outline

Chapter 1 consists of introduction to the project. In this section, a brief general background is presented. The objectives of the project are clearly phased with details. The research scope and methodology background are also presented.

Chapter 2 presents the first part of the literature review. There are two sections in this chapter. Section one presents an introduction to the satellite communication systems, frequency spectrum, satellite communications features, and satellite propagation impairments are also provided. Section two explains brief details about Rainfall distribution models, background on the characteristic of rainfall structure, included Malaysia climates and the vertical profile of rainfall are presented also.

Chapter 3 is the second part of the Literature review. Includes the descriptions of the basic concepts of the prediction models, the latest developments in the modeling over terrestrial and slant path, techniques for the evaluation of propagation degradation with theory background, emphasis is placed on promising modeling for prediction techniques are reviewed and the ITU-R world wide model for rain attenuation, and effective bath length along horizontal reduction and vertical adjustment factors are also presented.

Chapter 4 represents the methodology of the project. Including the details handling and the flow of processing for each step of the methodology for rain rate modeling, specific attenuation, effective horizontal path and effective rain height are also presented.

Chapter 5 presents the results and discussions for the methodology steps. Comparison is also done in this chapter for verification. Discussion for the simulation program and discussion of the rainfall rate and rain attenuation models performance is presented.

Chapter 6 concludes the thesis. The conclusion is given based on the analysis of results from the previous chapter. Recommendations for future works are also presented.

program for prediction of rain attenuation in both satellite and terrestrial paths during heavy rainfall event in Malaysia.

6.2 Future work

To complement and extend the result further, the following suggestions are made

- i. It is recommended to conduct more continued rainfall measurements in UTM –Skudai and various places in Malaysia using rain gauges and radar reflectively. For better understand of spatial and temporal structure of rainfall.
- ii. More rain attenuation measurements are recommended at different frequencies band and elevation angel for all the path geometry to enhance the proposed prediction model.
- iii. More work on ITU-R databank are recommended (DBSG5) for signal propagation in tropical countries.
- iv. More work in the adapted Matlab program of the rain height proposed model for allowing process of more on verifications data.

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